NASA
Technical Memorandum 101310

AVSCOM
Technical Memorandum 88-C-006

T55-L-712 Turbine Engine Compressor Housing Refurbishment—Plasma Spray Project

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(NASA-TM-101310) T55-L-712 TURBINE ENGINE COMPRESSOR HOUSING REFURBISHMENT-PLASMA SPRAY PROJECT (NASA) 44 p CSCL 11F

N89-10156

Unclas
G3/26 0168490

October 1988

US ARMY
AVIATION
SYSTEMS COMMAND
AVIATION R&T ACTIVITY

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E-4301

SUMMARY

A study was conducted to assess the feasibility of reclaiming T55-L-712 turbine engine compressor housings with an 88 wt % aluminum-12 wt % silicon alloy applied by a plasma spray process. Tensile strength testing was conducted on as-sprayed and thermally cycled test specimens which were plasma sprayed with 0.020 to 0.100 in. coating thicknesses. Satisfactory tensile strength values were observed in the as-sprayed tensile specimens. There was essentially no decrease in tensile strength after thermally cycling the tensile specimens. Furthermore, compressor housings were plasma sprayed and thermally cycled in a 150-hr engine test and a 200-hr actual flight test during which the turbine engine was operated at a variety of loads, speeds, and torques. The plasma sprayed coating system showed no evidence of degradation or delamination from the compressor housings.

As a result of these tests, a procedure was designed and developed for the application of an aluminum-silicon alloy in order to reclaim T55-L-712 turbine engine compressor housings.

INTRODUCTION

Currently, approximately 100 turbine engine compressor housings a year that are processed at the Corpus Christi Army Depot are out of tolerance because of corrosive pitting and nonconformance to dimensional specifications. These compressor housings cannot be reclaimed without additions of materials.

The purpose of this program was to evaluate a two-layer coating system which consists of a 95 wt % Ni-5 wt % Al bond coat and an 88 wt % Al-12 wt % Si alloy overcoat for use in reclaiming housings. The two-layer coating system is applied to the compressor housings by means of the plasma spray process. The plasma spray process was chosen because the resulting coating systems have high interparticle cohesion as well as excellent adhesion to a variety of materials.

The plasma sprayed compressor housings were subjected to a 150-hr simulated engine test and a 200-hr actual flight test in order to qualify the two-layer coating system for service aboard CH-47D helicopters.

Appendix A, written by Carl Reitenbach, George W. Leissler, George Gilchrist, and Cliff Darling, describes the compressor housing refurbishment procedure in detail. Appendix B by J. Kozub is the test specification for the 150-hr endurance and 10-hr emergency power test.

MATERIAL REQUIREMENTS AND COMPOSITION

The materials needed to effect repairs to the compressor housings must meet the following requirements:

(1) Possess a thermal expansion coefficient similar to alloy number HZ32A (AMS 4447), which is the magnesium alloy used in the construction of the housing

(2) Have the ability to withstand 370 °C in air for 12 hr

(3) Provide good bonding to ASM 4447 and have the capability of being applied at thicknesses up to 0.100 in.

(4) Allows a means to bring all out-of-tolerance surfaces (e.g., pilot diameters, end-to-end face surface dimensions, impeller curves, and stator vane landings) back to original dimensions.

The material chosen to reclaim the Textron Lycoming T55-L-712 compressor housings was an 88 wt % Al-12 wt % Si alloy. This material meets or exceeds all of the requirements outlined above and conforms to Textron Lycoming specification number M3962A.

A bond coat is necessary to provide higher bond strength characteristics to the compressor housing. The bond coat chosen was a 95 wt % Ni-5 wt % Al composite which meets Textron Lycoming specification number M3951 (ref. 1).

The 88Al-12Si alloy is similar in composition to aluminum alloy number 4032, which has an additional 0.5 wt % Si for a total of 12.5 wt % silicon. The thermal expansion coefficient for the number 4032 alloy is 20.3 in./in./°C (ref. 2) from +20 to +200 °C. The above figures indicate that the 88Al-12Si alloy is a close match in thermal expansion to the HZ32A magnesium alloy used in the housing; the latter alloy has a thermal expansion coefficient of 26.7 in./in./°C from +20 to +200 °C (ref. 3).

This report recommends that the plasma spray process be used to add material to the turbine engine compressor housings so that they may be reclaimed. This process was chosen because the resulting coating systems have high interparticle cohesion as well as excellent adhesion to a variety of materials.

The author has established a minimum tensile strength requirement for this program of 3000 psi, which is representative of a high integrity plasma sprayed aluminum-silcon coating system.

PRELIMINARY TESTING

Test Specimens and Procedures

Tensile testing. - The tensile tests were done according to American Society of Testing Materials (ASTM) C-633-79, entitled Standard Test Method for Adhesion of Cohesive Strength of Flame Sprayed Coatings. Fifty ASTM 447 specimens with diameters $\geq$ 1 in., with no more than 0.005 in. variation, were bond-coated on one end by plasma spraying with 0.005 in. $\pm$0.001 in. of 95Ni-5Al composite powder and were overcoated with the 88Al-12Si alloy. Thicknesses of the 88Al-12Si alloy coating were varied as follows:

(1) Ten specimens at 0.020 in. $\pm$0.001 in.
(2) Ten specimens at 0.040 in. $\pm$0.001 in.
(3) Ten specimens at 0.060 in. $\pm$0.001 in.
(4) Ten specimens at 0.080 in. $\pm$0.001 in.
(5) Ten specimens at 0.100 in. $\pm$0.001 in.

The surface area of the plasma sprayed magnesium specimens was calculated from the equation

$$A = \frac{\pi D^2}{4}$$

where D is the diameter.

Thermal cycling. - To evaluate the effect of thermal exposure on the plasma sprayed coating system applied to magnesium compressor housing samples, each set of samples was subjected to five individual test conditions. Each set consisted of five samples of the following coating thicknesses: 0.020, 0.040, 0.060, 0.080, and 0.100 in. A type-R thermocouple was used to verify sample temperatures that were attained during testing; however, the specimens in Group 1 were not thermocoupled during the liquid nitrogen quench. Test conditions were as follows:

Condition (1) The specimens were heated in a CM, Inc.[1] rapid response furnace to 370 °C and then quenched in liquid nitrogen. This process was repeated approximately 15 times.

Condition (2) Each specimen was heated from ambient conditions to 370 °C and forced-air-quenched back to ambient conditions. This process was repeated approximately 15 times.

Condition (3) Each specimen was heated to 120 °C; then the furnace was heated rapidly to 300 °C after which the specimens were allowed to cool to 120 °C. This process was repeated approximately 15 times.

[1]CM, Inc., 101 Dewey Street, Bloomfield, NJ 07003.

Condition (4) Each specimen was heated to 120 °C; then the furnace was ramped to 300 °C and held at this temperature for 6 hr to simulate a flight duration. This process was not repeated.

Condition (5) The specimens were placed in the furnace, while the temperature was ramped from ambient conditions to 370 °C, and held at this temperature for 12 hr. This process was not repeated.

Metalography. - The following metalographic preparation procedure was established by Metco, Inc.,[2] and provided for this program. All polishing was done by hand.

(1) Wet-grind the sample on silicon carbide papers (discs) with grits of 180, 240, 320, 400, and 600 respectively, while using water as a coolant. Each successive paper is used to remove the scratches from the previous, coarser grit paper. (The sample should be held so that grinding is perpendicular to the coating, and the coating is compressed against the substrate).

(2) Polish the sample on a silk cloth (A. Buehler, Ltd.,[3] number 40-7408) that is lightly charged with a 6-μm diamond compound. Polish out the 600-grit scratches by holding the sample 90° to the previous scratches with the wheel speed at approximately 550 rpm.

(3) Polish the sample on a 3-μm diamond-charged silk cloth to remove the 6-μm scratches. Use a small amount of lapping oil (similar to A. Buehler, Ltd.,[3] number 60-3250) to keep cloths slightly damp in steps 2 and 3.

(4) Fine-polish on a felt-type cloth (A. Buehler, Ltd.,[3] microcloth number 40-7208) impregnated with a 1-μm diamond compound. Keep the cloth relatively moist with an alcohol-based extender. Remove 3-μm scratches by alternating direction of polishing every 5 to 7 sec while the wheel is turning at a slow speed of approximately 175 rpm. Do not rotate the sample on the cloth. A fresh application of diamond may have to be applied for each sample.

(5) Final-polish the sample on a Buehler, Ltd.,[3] Selvyt cloth number 40-7008 (or similar cloth) that is charged with 0.5-μm diamond compound. A slow wheel speed should be used, and an alcohol-based diamond extender should be applied to the cloth while polishing out fine 1-μm scratches. Note that, a water-based diamond extender (such as Buehler, Ltd.,[3] metadi fluid number 40-6016) may be preferable to an alcohol-based extender in order to prevent anodic etching of the magnesium substrate material.

Test Results

Tensile testing. - The results of the tensile test on the as-sprayed 88Al-12Si alloy showed that all failures were observed to be cohesive-adhesive near or at the bond coat-top coat interface (ref. 4). The failure

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[2]Metco, Inc., 1101 Prospect Road, Westbury, NY 11590.
[3]Buehler Ltd., 41 Waukegan Road, Lake Bluff, IL 60044.

was termed cohesive-adhesive because the 88Al-12Si coating fractured away from the bond coat leaving some residual coating behind in nearly every case.

The equation used to find the actual tensile strength is

$$UTS = \frac{L}{A}$$

where UTS is the cohesive or adhesive strength per unit of surface area, L is the load to failure-force, and A is the cross-sectional area of the specimen.

The actual tensile strength, average tensile strength, and standard deviation for each as-sprayed specimen are shown in table I.

TABLE I. - TENSILE STRENGTH FOR AS-SPRAYED SPECIMENS

Group number	Coating thickness	Samples					Average tensile strength, psi	Standard deviation, S
		1	2	3	4	5		
		Actual tensile strength, psi						
1	0.020	4968	4854	4268	3919	3461	4294	633
2	0.040	4573	(a)	5013	5273	3753	4653	666
3	0.060	5045	4778	4020	5032	4796	4734	419
4	0.080	(a)	(a)	3685	3651	3822	3719	372
5	0.100	4841	5108	4453	4822	4682	4781	240

[a]Mg substrate failed prior to tensile failure of plasma sprayed coating system.

An overall common standard deviation calculated from the standard deviations squared is 466 psi.

Epoxy specimens (no plasma spray coating applied) were run at the same time that all of the other specimens were prepared. Five specimens were prepared. Stainless steel 1-in. diameter by 2-in. long slugs were grit blasted with 20-grit alumina media and epoxied together. The average tensile strength of the epoxy was 6899 psi.

Thermal cycling. - Each test condition had one specimen of each coating thickness from 0.020 to 0.100 in., that is, a total of five specimens per condition. Again, all of the specimens were observed to have failed in the cohesive-adhesive mode at the bond coat-top coat interface. The same equation used in the as-sprayed tensile test is applicable here. The actual tensile strength for each specimen is shown in table II.

TABLE II. - TENSILE STRENGTH FOR AS-SPRAYED

SPECIMENS UNDER VARIOUS TEST CONDITIONS

Sample set	Coating thickness	Test condition (Sample number)			
		1(6)	2(7)	3(8)	4(9)
		Tensile strength, psi			
1	0.020	5483	5376	5318	5592
2	0.040	4127	4701	4612	2790
3	0.060	4408	3248	3975	4542
4	0.080	3694	3962	3758	4153
5	0.100	4453	4127	4275	4382

After thermal cycling none of the treated specimens showed evidence of delamination or spallation before tensile testing.

Metalography. - The attached photomicrographs are representative of Metco, Inc.,[4] standard plasma sprayed, argon/hydrogen and nitrogen/hydrogen parameter sets number 3 and 4 for both the 88Al-12Si alloy and the 95Ni-5Al composite powder (see figs. 1 and 2). Also included are the photomicrographs of the sprayed thermally cycled and metalographic specimens along with the tensile specimens (see figs. 3 and 4).

Summary Of Preliminary Test Results

Since the tensile strength of the plasma sprayed 88Al-12Si alloy was comparable to that of the as-sprayed 88Al-12Si alloy, it seems not to have been affected by the thermal cycling test. However, there appears to have been a slight decrease in tensile strength caused by thermal cycling when the coating thickness was increased from 0.020 to 0.100 in. Worst case reclamation of the T55-L-712 compressor housings is considered to be 0.100 in. The tensile data suggest that this coating system is feasible for even worst case reclamation.

It is recommended that the Corpus Christi Army Depot implement a quality control baseline, that is, plasma spraying of metalography samples each time compressor housings are processed; and further, that tensile test specimens also be sprayed so that tensile tests can be performed at random intervals when the compressor housings are being processed. In order to maintain coating reproducibility and integrity, it is very important when plasma spraying to treat each variable of the plasma spray process as critical.

ENGINE TESTING

150-Hr Endurance and 10-Hr Emergency Power Test

An out-of-tolerance T55-L-712 turbine engine compressor housing was brought into compliance with the required dimensions at the Corpus Christi Army Depot by the plasma spray procedure. The compressor housing was installed in a plasma spray booth and sprayed with a computer-controlled robotic arm according to the procedure specified in appendix A.

After plasma spraying the compressor housing, the assembly of the turbine engine was continued as detailed in paragraph 5-418 in Depot Maintenance Work Requirement (DMWR) 55-24840-254. Once assembled, the turbine engine was installed in an engine test cell and tested according to the Textron Lycoming Test Specification XTS 512.1.8 for the 150-hr endurance and 10-hr emergency power test outlined in appendix B.

After completion of the 150-hr test the engine was disassembled, and the compressor housing halves were visually inspected for evidence of coating degradation or delamination. No evidence of coating failure was noted.

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[4]Metco, Inc. 1101 Prospect Road, Westbury, NY 11590.

After completion of the visual inspection, one of the compressor housing halves was shipped to the U.S. Army Propulsion Directorate at NASA Lewis Research Center where it was processed into samples for metalographic inspection according to the procedure specified in the section Metalography. The results of the metalographic inspection (see fig. 5) revealed no significant defects that could not have been prevented by following the procedure specified in appendix A, and by implementing the quality control baseline recommended in the section Summary of Preliminary Test Results.

200-Hour Flight Test

An out-of-tolerance T55-L-712 turbine engine compressor housing was brought into compliance with the required dimensions at Corpus Christi Army Depot by the plasma spray procedure. The compressor housing was installed in a plasma spray booth and sprayed with a computer-controlled robotic arm according to the procedure specified in appendix A.

After plasma spraying the compressor housing, the assembly of the turbine engine, in conjunction with a modified engine torque indicating system, was continued as described in paragraph 5-418 in DMWR 55-2840-254. The engine was flown for a 200-hr flight test by the U.S. Army Aviation Development Test Activity, Fort Rucker, AL, under the direction of the U.S. Army Test and Evaluation Command at the request of the CH47 Modernization Project Manager. The flight test consisted of numerous takeoffs, landings, hovering maneuvers, and flight demonstrations during which the engine was operated at a variety of loads, speeds, and torques.

After completion of the 200-hr test the engine was disassembled, and the compressor housing halves were visually inspected for evidence of coating degradation or delamination. No evidence of coating failure was noted.

After completion of the visual inspection, one of the compressor housing halves was shipped to the U.S. Army Propulsion Directorate at NASA Lewis Research Center where it was processed into samples for metalographic inspection according to the procedure specified in the section Metalography. The results of the metalographic inspection (fig. 5) revealed no significant defects that could not have been prevented by following the procedure specified in appendix A and by implementing the quality control baseline recommended in this report (see Summary of Preliminary Test Results). Refer to photographs in figure 6.

Summary Of Engine Test Results

The metalographic inspections revealed that the plasma sprayed 88Al-12Si coating was affected by neither the 150-hr engine test nor the 200-hr flight test. These inspections showed that the plasma sprayed coating system is feasible for reclaiming out-of-tolerance T55-L-712 turbine engine compressor housings.

CONCLUSIONS

The thermally-cycled, tensile-tested specimens met the author's minimum tensile strength requirements. The metalographic specimens from the 150-hr engine and 200-hr flight tests revealed no significant defect that could not have been eliminated by following the procedures specified herein. Therefore, the following recommendations are made:

1. The application of 88 wt % aluminum-12 wt % silicon alloy by a plasma spray process should be incorporated into the overhaul procedure to reclaim out-of-tolerance T55-L-712 turbine engine compressor housings.

2. The Corpus Christi Army Depot should implement a quality control baseline; that is, plasma spraying of metalography samples each time compressor housings are processed.

3. Tensile-test specimens should also be sprayed in order that tensile tests may be performed at random intervals when the compressor housings are being processed.

4. These tensile-test samples should have a minimum tensile strength of 3000 psi.

It is especially important to note that in order to ensure coating reproducibility and integrity each variable of the plasma spray process (such as maintaining kilowatts, spray distance, spray rates, primary and secondary gas flows, and traverse speeds) must be treated as critical.

ACKNOWLEDGMENT

The U.S. Army AVSCOM wishes to acknowledge the contributions of the following inidividuals: Carl Stearns of the NASA Lewis Environmental Durability Branch, who provided the services of George Leissler, Sverdrup Technology, Inc.; Robert Davies and the NASA Lewis Analytical Science Branch, who provided metalographic analyses of the samples; and Joseph Certo of the AVSCOM Propulsion Directorate, who processed and expedited the close-out phase of this project.

Appendix A

T55-L-712 COMPRESSOR HOUSING REFURBISHMENT PROCEDURE

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INTRODUCTION

These procedures describe the requirements and preparations for reclaiming compressor housings utilizing a plasma spray process.

REFERENCE DOCUMENT

The following procedure has been structured from the Depot Maintenance Work Requirements (DMWR No. 55-2840-254) dated 28 September 1984, a Plasma Spray Procedure developed specifically for use with Metco, Inc., equipment by George W. Leissler, Engineering Associate V., Sverdrup Technology Incorporated, and process refinements developed during specimen testing by George Gilchrist and Cliff Darling of the Production Engineering Department at Corpus Christi Army Depot.

NOTE

Due to possible variations in the DMWR procedures versus actual modified procedures used by depot personnel, revisions to this procedure to interface with current work requirements are permitted. These revised steps must be documented and approved by the appropriate authority.

COMPRESSOR HOUSING REFURBISHMENT PROCEDURE

INTRODUCTION

To begin this process reference section XIV of DMWR 55-2840-254, page 5-774.

_____ Perform disassembly of compressor housing and vane assembly as described in paragraph 5-414 and complete steps a. through m.

_____ Perform cleaning of compressor housing and vane assembly as described in paragraph 5-415.

_____ Perform inspection of compressor housing and vane assembly as described in paragraph 5-416.

5-417. REPAIR OF COMPRESSOR HOUSING AND VANE ASSEMBLY.

_____ Replace step e. with the following procedure.

e. Housing assembly (compressor) (99, figure 5-311).

_____ (1). Perform removal of Engine Gray Enamel using steps g. Method B. items (1a), (1b), or (1c). (Reference SP No. 6022 in appendix D, DMWR 55-2840-254).

_____ (2). Vapor degrease compressor housing using Trichloroethane (item 252 in appendix C, DMWR 55-2840-254 or equal).

_____ (3). Ensure removal of all residue from the compressor housing using clean dry air.

_____ (4). Perform step e. items (1), (3a), and (3b) in DMWR 55-2840-254, paragraph 5-417.

_____ (5). Perform step e. items (4a) and (4b) in DMWR 55-2840-254, paragraph 5-417.

_____ (6). Perform step e. items (6a through 6f) in DMWR 55-2840-254, paragraph 5-417.

_____ (7). Perform step e. item (7a) and (7b) in DMWR 55-2840-254, paragraph 5-417.

5-417 (cont.)

REFERENCE ITEM (8) IN DMWR 55-2840-254 AND REPLACE OR INSERT THE FOLLOWING STEPS AS INDICATED

(8). Repair compressor housing to restore dimensions by plasma spray method as follows:

PREMACHINING:

NOTE:

ENSURE THAT COMPRESSOR HOUSING CASE HALVES HAVE MATCHING SERIAL NUMBERS.

_______ (a). Place housing assemblies (99, figure 5-311) in a suitable locating fixture and center on a vertical turret lathe or equivalent.

_______ (b). Position contour gage template assembly LTCT11420, or equivalent, in trace section of vertical turret lathe.

_______ (c). Bring cutting tool into contact with housing assembly at location A (see figure 5-319) and bring tracer stylus into contact with template at corresponding location.

_______ (d). Raise tracer, as necessary, to machine contour to obtain a .017 inch minimum plasma spray buildup thickness after final machining and painting. Up to .050 inch maximum thickness is permissible. Check contour with gage LTCT11421 or equivalent. Cleanup as required from location A to O, figure 5-319.

_______ (e). The following areas of the compressor housing requiring restoration must also be machined to obtain a .017 minimum plasma spray buildup thickness after final machining. (Reference figure 5-318 for final dimensional specifications and locations.)

_______ 1. Compressor housing I.D. in vane assembly and insert mounting area.

_______ 2. Compressor housing pilot diameters A and K.

_______ 3. Compressor housing end to end face surface dimensions (refer to 12.512/12.502 dimension in figure 5-318).

_______ (f). Treat all machined surfaces with chromic acid solution (item 226 in appendix C, DMWR 55-2840-254).

______ (g). Clean housing assembly by vapor degreasing method (reference SP No. 3000 in appendix D, DMWR 55-2840-254).

PLASMA SPRAY CONSOLE SETTINGS:

______ (a). Set the following parameters for application of the 450-NS bond coat.

* Arc amps. - 500 ± 10
* Arc volts - 67 ± 3
* Use wheel type S
* Kilowatt output - up to 40 kW
* Set turntable speed to 100 rpm

(b). Set the primary and secondary gas pressures and flows, with the exhaust system on, as follows:

1. Set the primary gas pressure at 100 psi. (ARGON)

2. Set the primary flow at 80 CFM.

3. Set the secondary gas pressure at 50 psi. (HYDROGEN)

EXTREME CAUTION:

THE SECONDARY GAS FLOW VALVE MUST REMAIN CLOSED UNTIL THE HIGH FREQUENCY IGNITION OCCURS AND THE PLASMA SPRAY GUN IS AT FULL OPERATION. FAILURE TO FOLLOW THIS PROCESS WILL RESULT IN GUN FAILURE OR EXPLOSION.

4. Slowly introduce secondary gas flow while maintaining machine amperage, and set at 15 ± 5 CFM, to achieve operating voltage.

______ (c). Set the carrier gas flow at 37 CFM.

______ (d). Set the spray rate at 9 pounds per hour ± 1 pound per hour.

______ 1. Set the powder feed (using powder port number 2) for the spray gun as follows:

*. Ensure the carrier gas flow has been set.

*. Weigh a clean dry container sufficient to hold 2.5 lbs. of Metco 450-NS powder (item 5 attachment A.

*. Allow the powder feed to stablize after startup (approx. 1 to 3 minutes), then feed the powder into the container for (1) minute.

*. Reweigh the container with the contents.

*. The result of the container weight with powder minus the empty container weight (tare) is equal to grams per minute spray rate. To obtain lbs/hr. spray rate multiply grams per minute by .13228.

GRIT BLASTING:

MANDATORY:

IT IS REQUIRED THAT THE PLASMA SPRAYING BE DONE WITHIN 90 MINUTES AFTER SURFACE PREPARATION IS COMPLETE. IF THIS IS NOT POSSIBLE TREAT ALL EXPOSED SURFACES WITH CHROMIC ACID SOLUTION, (item 226 in appendix C, DMWR 55-2840-254) TO PREVENT OXIDATION OF THE MAGNESIUM HOUSINGS. THIS SOLUTION MUST BE REMOVED ON SURFACES THAT REQUIRE MATERIAL ADDITION BEFORE PLASMA SPRAYING. (Refer to Grit Blasting section of this procedure.)

CAUTION:

GRIT BLASTING PRESSURE HAS BEEN PRE-DETERMINED USING THE FOLLOWING METHOD:

*Use a magnesium test sample to determine pressure level setting.

*Set the pressure at a suitable level which does not permit grit entrapment into the base material. A 10 power microscope shall be required to inspect the compressor housing surfaces for grit entrapment. If entrapment occurs, lower pressure level and repeat this procedure until a satisfactory pressure has been reached.

______ (a). Set grit blasting machine pressure at 70 psi., 5 inches from the surface.

______ (b). Grit blast areas requiring material addition with angular steel grit (reference item 4 of attachment A).

(c). Remove all residual grit and foreign particles from compressor housing using clean dry air.

5-417 (cont.)

MASKING:

NOTE:

ALL AREAS OF THE COMPRESSOR HOUSING NOT REQUIRING MATERIAL ADDITIONAL ARE TO BE MASKED TO PREVENT HOT PARTICLES FROM THE PLASMA SPRAY PROCESS FROM BONDING TO THESE AREAS.

ANTI-BOND IS WATER SOLUABLE. DURING STORAGE SEGRAGATION OF THIS COMPOUND IS COMMON. IF THIS OCCURS RESTORE CONSISTENCY AS REQUIRED BY STIRRING IN SMALL QUANTITIES OF WATER.

_______ (a). Apply tape maskent (NSN 7510-00-X86-0695, item number 6, attachment A)

(b). For brush-on application, prepare anti-bond as follows:

1. Mix anti-bond thoroughly adding water to thin if necessary until the mixture will give a consistency similar to "No Drip Latex Paint". Check consistency by dipping a 1/2 inch dowel into the anti-bond and observe mixture runoff. Runoff should be 2-10 drops a minute.

CAUTION:

DURING APPLICATION OF THE ANTI-BOND COMPOUND, IF THE MIXTURE RUNS, THICKEN MIXTURE BY THE ADDITION OF ANTI-BOND AND STIR THOROUGHLY.

2. Apply with paint brush using suitable care to provide a uniform coating.

_______ (c). Apply one coat of anti-bond (item number 1, attachment A) to all smooth areas not requiring plasma spraying.

_______ (d). Apply two coats of anti-bond (reference item 1 of attachment A) to grit blasted areas not requiring plasma spraying.

CAUTION:

EACH COAT OF THE ANTI-BOND MUST DRY THOROUGHLY BEFORE APPLICATION OF THE SECOND COAT. THE ANTI-BOND WILL DRY AT ROOM TEMPERATURE (78 deg F) IN APPROXIMATELY (15) MINUTES. THE ANTI-BOND WHEN DRY WILL BE BLUE-BLACK IN COLOR.

5-417 (cont.)

PLASMA SPRAYING:
(450 Bond Coat)

MANDATORY:

IT IS REQUIRED THAT PLASMA SPRAYING BE DONE WITHIN 90 MINUTES AFTER SURFACE PREPARATION. IF THIS IS NOT POSSIBLE, TREAT ALL EXPOSED SURFACES WITH CHROMIC ACID SOLUTION (item 226 in appendix C, DMWR 55-2840-254) TO PREVENT OXIDATION OF THE MAGNESIUM HOUSINGS. THIS SOLUTION MUST BE REMOVED ON SURFACES THAT REQUIRE MATERIAL ADDITION BEFORE PLASMA SPRAYING. (Refer to Grit Blasting section of this procedure).

EACH PROCESS VARIABLE OF THE PLASMA SPRAY PARAMETERS MUST BE RIGIDILY CONTROLLED SO THAT THE COATING INTEGRITY AND REPRODUCIBILITY CAN BE MAINTAINED.

CAUTION:

DURING PLASMA SPRAYING OF THE COMPRESSOR HOUSING, IT IS REQUIRED THAT THE BASE MATERIAL TEMPERATURE BE KEPT UNDER 300 DEG. F

NOTE:

OVERHEATING OF THE BASE MATERIAL CAN BE IDENTIFIED BY DISCOLORATION OF THE ANTI-BOND ADJACENT TO THE SURFACE BEING SPRAYED. (Anti-bond will appear brownish in color.)

INSTRUMENTATION OF THE COMPRESSOR HOUSING BASE MATERIAL CAN BE DONE WITH A THERMAL SENSING DEVICE MOUNTED ON THE OPPOSITE SIDE OF THE SURFACE BEING SPRAYED. THIS WILL PROVIDE AN ACCURATE TEMPERATURE MEASUREMENT.

IF BASE MATERIAL OVERHEATING OCCURS, ADDITIONAL COOLING JETS WILL BE REQUIRED TO LOWER BASE MATERIAL TEMPERATURE.

(a). Place compressor housing (99, figure 5-311) in a suitable fixture in plasma spray area.

_______ (b). Position plasma spray gun (type 3MBT), with Metco nozzle type GH, powder port and insulator perpendicular to the housing surface.

_______ (c). Set the spray distance from the gun to surface at 5 inches ± 1 inch.

_______ (d). Plasma spray areas requiring material addition with Bond coat, Metco 450-NS, (item number 5, attachment A) at a deposition rate of .0004 - 0006 inch per pass to a final thickness of .004 - .006 inch.

_______ (e). Perform the following sequence to shutdown the plasma spray machine.

_______ 1. Depress console powder feed off button.

2. Keeping amperage constant, close the secondary gas flow valve.

3. Reduce amperage to "0".

4. Depress run button off on the control panel.

5. Purge primary gas through the plasma gun for 1 to 2 minutes to keep the electrode from oxidizing while cooling.

6. Allow compressor housing to cool below 100 °F.

7. Turn auxiliary and cooling air off.

PLASMA SPRAYING:
(P 52C-10)

_______ (a). Set the following parameters for application of the P52C-NS coating system, set #4.

* Arc amps. - 500 ± 10

* Arc volts - 67 ± 3

* Use wheel type H

* Kilowatt output - 33.5 ± 1.5 kW

* Set turntable speed at 100 rpm

______ (b). Set the primary and secondary gas pressures and flows, with the exhaust system on, as follows:

______ 1. Set the primary gas pressure at 100 psi. (ARGON GAS)

______ 2. Set the secondary gas pressure at 50 psi. (HYDROGEN GAS)

______ 3. Set the primary flow at 80 CFM.

<u>EXTREME CAUTION</u>:

THE SECONDARY GAS FLOW VALVE MUST REMAIN CLOSED UNTIL THE HIGH FREQUENCY IGNITION OCCURS AND THE PLASMA SPRAY GUN IS AT FULL OPERATION. FAILURE TO FOLLOW THIS PROCESS WILL RESULT IN GUN FAILURE OR EXPLOSION.

______ 4. Slowly introduce secondary gas flow while maintaining machine amperage, and set at 15.

______ (c). Set the carrier gas flow at 37 CFM.

______ (d). Set the spray rate at 10 pounds per hour $\pm$ 1 pound per hour.

______ 1. Set the powder feed (using powder port #1) for the spray gun as follows:

*. Ensure the carrier gas flow has been set.

*. Weigh a clean dry container sufficient to hold 2.5 lbs. of Metco P 52C-NS powder (item 3 of attachment A).

*. Allow the powder feed to stablize after startup (approx. 1 to 3 minutes), then feed the powder into the container for (1) minute.

*. Reweigh the container with the contents.

*. The result of the container weight with powder minus the empty container weight (tare) is equal to grams per minute spray rate. To obtain lbs/hr. spray rate multiply grams per minute by .13228.

_______ (e). Set the spray distance from the gun to the surface at 5 inches $\pm$ 1 inch.

_______ (f). Plasma spray areas requiring material addition with Metco 52C-NS at a deposition rate of .004 - .006 inch per pass to a finished coating thickness of .015 to .020 inch oversized from the desired final dimensions. <u>(Maximum coating thickness should not exceed .050)</u>.

<u>CAUTION:</u>

DURING PLASMA SPRAY OF THE COMPRESSOR HOUSING, IT IS REQUIRED THAT THE BASE MATERIAL TEMPERATURE BE KEPT UNDER 300 DEG. F

<u>NOTE:</u>

OVERHEATING OF THE BASE MATERIAL CAN BE IDENTIFIED BY DISCOLORATION OF THE ANTI-BOND ADJACENT TO THE SURFACE BEING SPRAYED. (Anti-bond will appear brownish in color.)

INSTRUMENTATION OF THE COMPRESSOR HOUSING BASE MATERIAL CAN BE DONE WITH A THERMAL SENSING DEVICE MOUNTED ON THE OPPOSITE SIDE OF THE SURFACE BEING SPRAYED. THIS WILL PROVIDE AN ACCURATE TEMPERATURE MEASUREMENT.

IF BASE MATERIAL OVERHEATING OCCURS, ADDITIONAL COOLING JETS WILL BE REQUIRED TO LOWER BASE MATERIAL TEMPERATURE.

_______ (g). Perform the following sequence to shutdown the plasma spray machine:

1. Depress console powder feed off button.

2. Keeping amperage constant, close the secondary gas flow valve.

3. Reduce amperage to "0".

4. Depress run button off on the control panel.

_______ 5. Purge primary gas through the plasma gun for 1 to 2 minutes to keep the electrode from oxidizing while cooling.

_______ 6. Turn spray gun off.

_______ 7. Allow housing to cool below 100 °F.

_______ 8. Turn auxiliary and cooling air off.

5-417 (cont.)

________ 9. Remove compressor housing from plasma spray area.

ANTI-BOND REMOVAL:

CAUTION:

DO NOT USE SOLVENTS OR DEGREASING AGENTS TO REMOVE ANTI-BOND.

________ (a). Remove tape type masking.

________ (b). Remove anti-bond with a suitable wire brush.

________ (c). Remove heavy overspray from material addition with a suitable wire brush.

POST MACHINING:

________ (a). File excess plasma spray material from compressor housing splitline to obtain sharp, square corners.

________ (b). Remove excess plasma spray material from the through holes in the compressor housing using a suitable reamer.

________ (c). Remove loose particles from the compressor housing with clean dry compressed air.

________ (d). Seal all plasma sprayed areas with Coricone sealer. (item 2 attachment A)

CAUTION:

DURING FINAL MACHINING ENSURE THAT THE COATING HAS NOT SEPARATED FROM THE BASE MATERIAL. (PULLOUT) IF PULLOUT IS EVIDENT ENSURE THAT THE MACHINING PARAMETERS USED, (ie., dull tool bits, excessive material removal, etc...) WERE NOT AT FAULT.

CAUTION:

FINAL MACHINED DIMENSIONS MUST INCLUDE A TOLERANACE FOR APPLICATION OF .001 to .002 SYNTHETESINE PAINT. (reference DMWR 55-2840-254, item 242 in appendix C)

________ (a). Final machine compressor housing areas that have been plasma sprayed to dimensions shown in DMWR (reference figure 5-318) as listed:

1. Machine centrifugal land area using location A and location O (figure 5-319) as contour gage points. Final check with contour gage or equivalent.

5-417 (cont.)

2. Compressor housing I.D. in vane assembly and insert mounting and area.

3. Compressor housing pilot diameters A,B,C,D, AND K.

4. Compressor housing end to end face surface.

(b). Redefine housing as having aluminum sprayed surfaces by adding an (-Ⓢ) after housing serial number.

CORROSION PREVENTION:

_______ (a). Treat all reworked aluminum surfaces with alodine solution (reference DMWR 55-2840-254, item 14 in appendix C), reworked magnesium surfaces with chromic pickle solution (reference DMWR 55-2840-254, item 226 in appendix C).

CONTINUE PROCESS OF COMPRESSOR HOUSING AND VANE ASSEMBLY REASSEMBLY PER PARAGRAPH 5-417 in DMWR 55-2840-254.

Attachment A

MATERIALS LIST

ITEM NO.	DESCRIPTION
1.	ANTI-BOND, METCO, INC. PRODUCTS NO. 12088
2.	SEALER, CORICONE, PRODUCTS NO. 1700 (NSN 8030-00-033-4291)
3.	PLASMA SPRAY POWDER, METCO, INC. 52C-NS, PRODUCT NO. 12108 (NSN 3439-01-130-2020)
4.	GRIT, STEEP, GRIT SIZE 25 (NSN 5350-00-271-5986)
5.	PLASMA SPRAY POWDER, METCO, INC. 450-NS, BOND COAT, PRODUCT NO. 10941. (NSN 3439-00-111-5937)
6.	TAPE, MASKING, (NSN 7510-00-X86-0695)

COMMERICAL SOURCES:

METCO, INC.
1101 PROSPECT ROAD
WESTBURY, NEW YORK 11590
PHONE: (516) 334-1300

CORICONE CORP.
550-T FRONTAGE RD
NORTHFIELD, ILL. 60093
PHONE: (312) 441-5800

APPENDIX B

AVCO LYCOMING TEST SPECIFICATION

XTS 512.1.8

150-HOUR ENDURANCE AND 10-HOUR EMERGENCY POWER TEST

T55-L-712

Prepared By: J. Kozub
T55 Test Engineer

Approved By: R. Hathaway
Engine Test Manager (Dev.)
Aircraft Turboshaft

May 1986

1. SCOPE

This specification describes the requirements for the conduct of a 150-hour endurance and 10-hour Emergency Power test of the T55-L-712 engine. These requirements are in compliance with the applicable portions of Specification AV-E-8593B, as amended by Avco Lycoming Prime Item Development Specification (PIDS) 124.53B

2. APPLICABLE DOCUMENTS

Military Specification AV-E-8593B.

Avco Lycoming Prime Item Development Specification 124.53, dated 18 December 1981, Revision B. Numbers in parenthesis at the end of paragraphs in this specification denote the applicable paragraph of the PIDS.

3. PRETEST REQUIREMENTS

3.1 Inspection: Engine parts, components, accessories, test apparatus and instrumentation shall be inspected, functionally tested and calibrated, as applicable, subject to witnessing by a representative of the Government. Said representative shall be given all reasonable facilities to determine conformance with this specification.

3.2 Test Engine: The particular engine intended for this test shall be officially designated by the contractor prior to start of the testing. The engine used for the tests specified herein shall be described using an approved parts list, and a list of parts not conforming to an approved parts list shall be provided. Feature items for which approval will be requested shall be identified.

3.2.1 Engine Weight: The dry weight of the completely assembled engine shall be determined and recorded prior to delivery to test (4.2.2.2).

3.2.2 Photographs: Photographs of the completely assembled engine shall be taken prior to test when the external appearance of the engine is altered by any part undergoing substantiation test. The photographs will be of sufficient number and clarity to describe the external appearance of the engine.

3.2.3 Engine Fuel System Calibrations: Prior to the initiation of the engine calibration, the following components of the fuel and power control systems shall undergo bench calibrations to determine conformance with the design tolerance range as defined in the applicable control specification.

Fuel control
Flow divider
Fuel manifolds
Start fuel solenoid
Start fuel nozzles

3.2.4 Temperature Sensing System Calibration: The measured gas temperature sensing system(s) shall be checked to establish its proper functioning over the range of conditions required in the model specification. The performance shall meet the design tolerance range required by the engine manufacturer. (4.5.1.1)

4. ENGINE TEST

4.1 Data

4.1.1 Accuracy of Data: For all engine and component calibrations and tests, reported data shall have a steady-state accuracy within the tolerances shown below.

Item of Data	Accuracy
Rotor Speeds	± 0.2 percent of the value at the intermediate rating
Power	± 1.0 percent of the value at the maximum rating
Fuel Flow	± 1.5 percent of the value being measured
Vibration	± 10.0 percent of specified engine limit, at the specified frequency
All other data	± 2.0 percent of the value being measured

Automatic recording equipment and associated test apparatus required to evaluate engine variables versus time shall have a static accuracy within ±2 percent of the values obtained at the intermediate rating of the engine. (4.2.2.1)

4.1.2 Steady-State Data During the 150-hour endurance test, except for the power transient runs, the following data shall be recorded where applicable, at intervals not greater than 30 minutes or once during each test period, whichever is shorter: (4.2.2.10)

Time of day
Total endurance
Control lever positions, degrees
*Exhaust nozzle area, sq. in. (cold, before and after test)
Gas producer speed, NI, % of 18,720 rpm
Power turbine speed, NII, % of 15,333 rpm
Shaft horsepower,shp
Torquemeter reading, lb-ft
Fuel consumption, lb/hr
*Bellmouth static pressure, in. H_2O gage
*Bellmouth total pressure, in. H_2O gage
Engine inlet total temperature, °F
Compressor discharge total pressure, psi or in. Hg gage
Compressor discharge total temperature, °F
Oil pressure at rear bearing inlet, psig
Oil temperature at pressure pump outlet, °F
Fuel pressure at fuel-system inlet, psig
Measured gas temperature, °F

Fuel temperature, °F
Engine case vibration at points shown on installation drawing, mils & in/sec
*Ignition source voltage (v) and current (amp), while starting
*Oil leakage at accessory pads

*Items so marked need be recorded during calibrations only.

4.1.3 Transient Data

4.1.3.1 Power Transient Data: During the calibrations, the following shall be recorded against time, using a suitable oscillograph, for power transients between ground idle and maximum and between flight idle and maximum. (4.2.2.11)

Power lever position, degrees
Gas producer speed, N_I, %
Power turbine speed, N_{II}, %
Compressor discharge total pressure, P_{t3}, psig
Fuel flow, W_f, lb/hr
Measured gas temperature, $T_{t4.5}$, °F
Output shaft torque, lb-ft

4.1.3.2 Starting Data: For each start performed on the test engine, the following data shall be recorded: (4.2.2.12)

Start number
Time to ground idle, seconds
Gas producer speed at idle, N_I, %
Maximum measured gas temperature during start, $T_{4.5}$,°F
Oil pressure (rear bearing inlet) at idle, psig
Engine inlet temperature, °F

In addition, the following parameters shall be measured during engine starts at the calibration and recalibration.

Time to ignition, seconds
Time to starter cutout, seconds
Gas generator speed at ignition, N_I, %
Gas generator speed at starter cutout, N_I, %
Total time during which the measured gas temperature exceds 1408°F
Control lever spindle position (in degrees)
Oil temperature at measuring point shown on the installation drawing, (oil bulb) °F
Time to stabilize to operating oil pressure, seconds
Fuel pressure at measuring point shown on the installation drawing, (boost pump inlet), psig

4.1.4 Barometer Readings: The barometer shall be read and recorded at intervals not exceeding three hours. (4.2.2.8)

4.1.4.1 Barometer Correction for Temperature: The barometer shall be corrected for temperature.

4.1.5 Miscellaneous Data: The date, operating schedule, engine model designation, and serial number shall be recorded on each log sheet. (4.2.2.3)

4.1.6 Test Notes: Notes shall be placed on the log sheets of all incidents of the run, such as leaks, vibration, any other irregular functioning of the engine or equipment, and corrective measures taken. (4.2.2.4)

4.1.7 Fuel and Oil Data: All oil additions made during the endurance test shall be recorded. Samples of the oil shall be taken from the engine for analysis at the end of the 8th cycle (48 hours) and 17th cycle (102 hours) and at the completion of the endurance test. Oil consumption rates, as determined by the net amount of oil added, shall be reported for each 48 or 52-hour period between sample removals. The oil samples removed from the engine, and a sample of unused oil, shall be analyzed for specific gravity, acid number, and kinematic viscosity at 38°C and 99°C. The lower heating value shall be determined for fuel samples taken at the beginning, approximate mid-point, and end of the endurance test. Specific gravity of the fuel shall be recorded daily. (4.2.2.6)

4.1.8 Corrections: Readings of shaft horsepower, rotor speed, airflow rate, fuel flow rate, specific fuel consumption, gas pressures, and gas temperatures will be referred to standard sea level atmospheric conditions as defined in U.S. Standard Atmosphere, 1962 (ASTIA Document 401813). The correct barometric pressure will be obtained from a barometer external to the test cell and will be corrected for the cell depression obtained by using a pressure pickup at the inlet to the engine. Ambient temperature will be measured by a chromel-alumel thermocouple fixed at the engine inlet. (4.2.2.9)

4.2 Test Apparatus

4.2.1 Test Equipment: The following equipment will be used to facilitate the conduct of the test:

4.2.1.1 Power Absorption: A waterbrake will be used to absorb the engine output shaft power. The brake is supported from the engine by an adapter having four beams strain gaged for torque sensing.

4.2.1.2 Starting System: A suitable hydraulic starter with hydraulic pressure supply of sufficient capacity will provide engine starting power.

4.2.2 Data Acquisition Equipment: The following apparatus shall be used to measure and record the required data. Where such equipment is available, an automatic data acquisition system may supplement or supplant the indicating devices noted below:

4.2.2.1 Output Shaft Torque: The support beams of the waterbrake mounting adapter are equipped with calibrated strain gages which sense the output torque. Conversion of strain gage signal to torque indication will be accomplished by suitable signal convertor.

4.2.2.2 Rotor Speeds: Rotor speeds will be measured by Standard Electric Time Corporation tachometers, electrically driven by MS 28054 tachometer generators, or by variable time base digital counters driven by a magnetic speed pickup.

4.2.2.3 Airflow: An inlet nozzle, with ASME-recommended geometry, will utilize throat static pressures and entry total pressures to measure airflow.

4.2.2.4 Pressures: Calibrated Bourdon tube gauges and/or transducers will measure pressures.

4.2.2.5 Temperatures: Temperatures will be measured by C.A. thermocouples. Indication will be by means of digital indicators in conjunction with appropriate signal conditioning equipment.

4.2.2.6 Fuel Flow: A calibrated turbine element with associated signal converter, amplifier and "readout" will be used for fuel flow measurement.

4.2.2.7 Vibration Measuring Equipment: The vibration measuring equipment will consist of Vibrametric, Model No. 14C, or CEC, Model No. 4-118, vibration pickups, in conjunction with a suitable vibration meter. The meter will have incorporated in its system appropriate filters. Displacement values, peak-to-peak amplitude in mils, and velocity, in/sec., will be recorded by a minimum of three vibration pickups mounted on the engine.

4.2.2.8 Transient Recording: An oscillograph recorder will be used during the engine calibration and recalibration phases to establish transient characteristics of the engine. The following variables versus time will be measured during these calibrations: (1) power lever position; (2) gas producer speed, N_I; (3) power turbine speed, N_{II}; (4) compressor discharge pressure, P_{t3}; (5) fuel flow, W_f; (6) measured gas temperature; (7) output shaft torque.

4.3 Operating Conditions

4.3.1 Test Conditions: Testing shall be conducted under sea level static conditions. Engine inlet temperature may be controlled, if necessary, to maintain the required turbine inlet temperatures.

4.3.2 Oil Inlet Temperature: The engine has an integral oil system, and oil bulb temperature is a function of inlet air and fuel temperature.

4.3.3 Oil Pressure: The oil pressure shall be adjusted to 70 ± 20 psig at 17,784 (95.0%) gas producer speed at 190°F oil bulb temperature.

4.3.4 Accessory Drives: The following accessories and engine components will be installed and run during the 150-hour endurance test:

I. Accessory Gearbox

1. Power control including fuel pump
2. Lubrication and scavenge pump
3. Gas producer tachometer-generator MS 28054 or magnetic pulse generator mounted on rear of lubrication pump
4. Power turbine speed indication signal generator
5. Fuel boost pump

II. Starter Gearbox

1. Starter with torque characteristics not exceeding the minimum applied torque specified in Figure 19 of the PIDS.

4.3.5 Oil Servicing: The oil system shall be drained and filled with new oil at the start of the test. Except for samples, oil shall not be drained from the engine prior to completion of the test unless authorized by the cognizant authority.

4.3.6 Filter Inspections: The impending bypass pop-up indicators on oil and fuel filters shall be observed at intervals not exceeding one cycle (6 hours). The fuel filter shall be replaced when actuation of the indicator is observed. The oil filter indicator shall be reset after first observation of actuation, and shall thereafter be observed at each shutdown for the next five hours. If reactivation has not occurred in that time, inspection period shall revert to the normal interval. The oil filter shall be replaced on second activation.

4.3.7 Fuel and Oil Grades: The endurance test may be performed using any combination of fuel and oil allowed by the PIDS. Jet A fuel is also permitted. Unless otherwise specified prior to test, the endurance test shall be conducted using MIL-T-5624, Grade JP-4 fuel and MIL-L-23699 oil.

4.3.8 Accreditable Test Time: Test time shall not be credited by increments shorter than 15 minutes except when shorter periods are a test requirement.

4.4 METHOD OF TEST

4.4.1 Engine Calibration: The procedure during the engine calibration shall be such as to establish the performance characteristics of the complete engine prior to the test. Except where otherwise specified, calibrations shall be made with no accessory power extraction, and with no bleed airflow. The following data shall be obtained:

4.4.1.1 Steady State Calibration: A steady state calibration shall be conducted to demonstrate compliance with the sea level performance ratings in Table II of the PIDS, Attachment I of this specification, and to establish the accuracy of the engine torquemeter indication. Data as required in 4.1.2 of this specification shall be recorded. The calibration shall include as a minimum, the following approximate power levels: maximum, intermediate, maximum continuous, 75% maximum continuous, 60% maximum continuous, 40% maximum continuous, flight idle, ground idle.

4.4.1.2 Transient Calibration: Data required in paragraph 4.1.3.1 of this specification shall be recorded to demonstrate the transient performance of the engine. During the transients there shall be no combustion instability or compressor instability. Control lever spindle motion shall be completed in 0.5 seconds or less. The time required to complete 95% of the power change shall not exceed the following at sea level standard day conditions:

a. From ground idle to maximum power available, 10.0 seconds.

b. From flight idle to maximum power available, 3.6 seconds.

c. From maximum power to ground idle, 8.0 seconds.

d. From maximum power to flight idle, 6.0 seconds.

Transients between ground idle and maximum shall be performed by moving the power lever between the ground idle and maximum power positions with the output shaft load set to produce approximately rated output shaft speed at the maximum power condition. The time required to accomplish 95% of the power change from idle to the lower of 3750 shp, or maximum power for the prevailing ambient temperature, shall be recorded as the acceleration time.

For the purposes of this calibration, flight idle may be established by determining the gas producer speed, N_I, from Figure 11 of the PIDS. Accelerations will be demonstrated and timed from the gas producer speed so determined using the power lever in the manner described above.

The change in compressor discharge pressure (P_3) will be utilized as the indication of the change in shaft horsepower for the purpose of determining transient times.

4.4.1.3 Starting Data: The data specified in 4.1.3.2 of this specification shall be recorded during starts at the time of the calibrations.

4.4.1.4 Recalibrations: After completion of the 150-hour test, a recalibration check run shall be made, following the procedures specified in 4.4.1.1 through 4.4.1.3 above. During this run, the power, corrected to sea level standard conditions, shall not be less than 95% of the initial calibration values, and the specific fuel consumption, corrected to sea level standard conditions, shall not exceed 105% of the initial calibration values. The engine shall meet all other specified performance requirements which can be checked by the calibration procedure.

4.4.2 150-Hour Endurance Test

4.4.2.1 Endurance Test Procedure: Following the calibration run, the engine shall be adjusted to produce at least the steady state maximum measured gas temperature limit, with the power lever spindle in the maximum power position and the values shall be re-established, as necessary, at the beginning of each cycle. During this test, the engine shall be adjusted as necessary to maintain measured gas temperatures at or above the corresponding maximum limits for each steady-state rated power condition. All of adjustments required shall be recorded.

a. For purposes of the endurance test, operation at maximum, intermediate and maximum continuous power shall be interpreted to mean operation at not less than the corresponding steady-state measured gas temperature limit

b. Minimum output shaft speed shall be interpreted as that output shaft speed at which the output shaft torque is not less than the torque limit plus the system inaccuracy limit for the applicable power condition or the minimum output shaft governing speed, whichever occurs first. Maximum output shaft speed shall be interpreted as the output shaft maximum speed limit or the output shaft maximum governing speed, whichever occurs first.

c. The test runs in each cycle shall be conducted in the order given. The time for changing power shall be charged to the duration time of the lower setting. The control lever spindle shall be advanced or retarded in not more than 0.5 seconds. During transient operations, the engine may be adjusted to normal operational settings, to avoid exceeding maximum limits, provided the adjustments are within the mechanical adjustment limits furnished with the engine. The developed powers at maximum power and ground idle conditions shall be as established by the engine controls.

   The maximum continuous power run, intermediate power run and high torque incremental run of the test cycle shall be conducted by adjusting the load to the required values while the engine is controlled by the output shaft speed governor.

4.4.2.2 150-Hour Endurance Test: This test shall consist of 25 cycles of six hours each. A minimum of 200 starts shall be made on the endurance test engine. Of these there shall be at least 25 starts, each preceded by a two-hour minimum shutdown; at least 10 false starts (a starting sequence without benefit of ignition) followed immediately after the permissible engine drainage time by a succesful start; and at least 10 "quick" restarts (a start within a maximum of two minutes time from a previous shutdown). If necessary, addtional starts to bring the total to 200 starts may be made at the end of the endurance test(s). The engine shall be shut down and started not less than six times each test cycle.

4.4.2.2.1 Test Cycle: Each cycle of the test shall consist of the following runs: (4.5.1.7)

(a) Maximum Power Run: One hour consisting of:

(1) Ten minutes at maximum power and at the output shaft speed schedule of 4.4.2.2.2

(2) Five minutes at ground idle power.
Repeat for a total endurance time of one hour per cycle.

(b) Maximum Continuous Power Run: One hour consisting of:

(1) Twenty minutes at maximum continuous power and at the maximum output shaft speed.

(2) Twenty minutes at maximum continuous power and at the rated output shaft speed.

(3) Twenty minutes at maximum continuous power and at the minimum output shaft speed.

(c) Intermediate Power Run: One hour consisting of:

(1) Thirty minutes at intermediate power and at the output shaft speed schedule of 4.4.2.2.2

(2) Five minutes at a measured gas temperature no higher than maximum continuous rated measured gas temperature.

(3) Twenty minutes at intermediate power and at the output shaft speed schedule of 4.4.2.2.2.

(4) Five minutes at a measured gas temperature no higher than maximum continuous rated measurements temperature.

d. Power Transient Run: One hour consisting of:

(1) Five minutes at ground idle power.

(2) Five minutes at intermediate power.

These periods to be repeated alternately for a total of one hour.

e. High Torque Incremental Run: One hour consisting of the following conditions, except that exceeding maximum power as defined in 4.5.1.4 of the PIDS will not be required:

(1) Fifteen minutes at the output shaft speed schedule of 4.4.2.2.2 and at the maximum continuous torque limit.

(2) Fifteen minutes at the output shaft speed schedule of 4.4.2.2.2 and at 90 percent of the maximum continuous torque limit.

(3) Fifteen minutes at the output shaft speed schedule of 4.4.2.2.2 and at 80 percent of the maximum continuous torque limit.

(4) Fifteen minutes at the output shaft speed schedule of 4.4.2.2.2 and at 60 percent of the maximum continuous torque limit.

(f) Low Torque Incremental Run: One hour consisting of the following conditions unless the required operation results in conditions unacceptable or impractical for the power absorption device, in which case conditions will be set as close as practicable to those required:

(1) Fifteen minutes at the output shaft speed schedule of 4.4.2.2.2 and at 40 percent of the maximum continuous torque limit.

(2) Fifteen minutes at the output shaft speed schedule of 4.4.2.2.2 and at 20 percent of the maximum continuous torque limit.

(3) Fifteen minutes at the output shaft speed schedule of 4.4.2.2.2 and at not more than three percent of the maximum continuous torque limit.

(4) Fifteen minutes at ground idle power and at not less than 10 percent of the maximum continuous torque limit.

A tabulation of required conditions is presented in Attachment II.

4.4.2.2.2 Output Shaft Speed Schedule: The output shaft speed schedule applicable to runs a, c, e, and f of the endurance test cycle is as follows:

(a) Maximum output shaft speed during the first through the fifth cycles.

(b) Rated output shaft speed during the sixth through the tenth cycles.

(c) Minimum output shaft speed during the eleventh through the fifteenth cycles.

(d) Rated output shaft speed during the sixteenth through the twentieth cycles.

(e) Maximum output shaft speed during the twenty-first through the twenty-fifth cycles.

4.4.3 Additional Test Procedures

4.4.3.1 Recalibration: Following completion of the 150-hour endurance test, a recalibration check shall be conducted in accordance with 4.4.1.4 of this specification

4.4.3.2 Inspection: Following the recalibration, the engine shall be disassembled sufficiently to inspect and document the condition of hot section components and reassembled. This disassembly may be performed in place on the test stand.

4.4.3.3 Emergency Power Test: After the inspection and reassembly, the engine shall be subjected to a 10-hour emergency power test (4.5.1.12)

4.4.3.3.1 Calibration and Adjustment: A steady-state calibration of the engine shall be performed, and shall include the following approximate power levels: 75% maximum continuous, maximum continuous, intermediate, maximum, and emergency. The engine shall be adjusted to produce at least the emergency power measured gas temperature limit with the power lever spindle in the emergency power position.

4.4.3.3.2 10-Hour Endurance Run: The test shall consist of 4 cycles of 2 1/2 hours each. For purposes of this test, operation at emergency, maximum, intermediate, and maximum continuous power shall be interpreted to mean operation at not less than the corresponding steady state measured gas temperature limit as defined in 4.4.2.1 (a).

The test cycle shall be as follows:

a. Power Transients - 20 minutes consisting of alternate periods of:

   5 minutes at Ground Idle
   5 minutes at Intermediate Power

b. Maximum Continuous power - 30 minutes at maximum continuous power and rated output shaft speed.

c. Intermediate Power: 15 minutes at intermediate power and rated output shaft speed.

d. Maximum Power Run: 15 minutes consisting of:

   5 minutes at Ground Idle
   10 minutes at Maximum Power and rated output shaft speed

e. Emergency Power: 30 minutes at emergency power and rated output shaft speed

f. Incremental Run: 40 minutes consisting of:

   10 minutes at 80% maximum continuous torque and maximum continuous output shaft speed

   10 minutes at 60% maximum continuous torque and maximum output shaft speed

   10 minutes at 40% maximum continuous torque and maximum output shaft speed

   10 minutes at 20% maximum continuous torque and maximum output shaft speed

A tabulation of required conditions is presented in Attachment III.

Oscillograph recordings as specified in 4.1.3.1 shall be obtained for at least one transient from maximum power to emergency power.

4.4.3.3.3 Recalibration: Following completion of the 10-hour emergency power test, a recalibration similar to the calibration of 4.4.3.3.1 shall be performed.

4.5 Posttest Requirements

4.5.1 Component Recalibrations:

4.5.1.1 Engine Control System Recalibration: After completion of the endurance test, the components of the engine control system shall undergo a bench recalibration to determine conformance with the design tolerance range required by the engine manufacturer. For this calibration, external engine control adjustments shall be established at their original bench calibration positions.

4.5.1.2 Temperature Sensing System Recalibration: After completion of the endurance tests, the measured gas temperature system shall be rechecked to establish its proper functioning. The performance shall meet the design tolerance range required by the engine manufacturer.

4.5.2 Teardown Inspection: After completion of the tests on the endurance test engine, the engine shall be disassembled as necessary for examination of parts undergoing substantiation testing to disclose excessively worn, distorted, or weakened parts. These measurements shall be compared with the contractor's drawing dimensions and tolerances or with similar measurements made prior to the test, when available.

5. REPORT

Following completion of the endurance tests, a report shall be submitted in accordance with PIDS 124.53B

T55-L-712
Performance Ratings at Sea Level, Static, Standard Conditions

Rating	Minimum Power (SHP) (hp)	Maximum Gas Generator Speed (Ng) (rpm)	Rated Output Shaft Speed (Np) (rpm)	Fuel Flow (W_f) (lb/hr)	Rated Output Shaft Torque (TRQ_p) (lb - ft)	Rated Gas Generator Turbine Inlet Temperature (Maximum) - (^oF)	Maximum Measured Gas Temperature (MGT) - (^oF)
Emergency	4,500	19,750	16,000	2340	1,477	2,050	1,670
Maximum	3,750	18,940	16,000	1988	1,230	1,885	1,525
Intermediate	3,400	18,620	16,000	1846	1,116	1,815	1,465
Max. Cont.	3,000	18,250	16,000	1686	988	1,740	1,405
75% Max. Cont.	2,250	17,440	14,400	1373	--	--	--
40% Max. Cont.	1,200	15,820	11,530	930	--	--	--
Flight Idle	0	13,100	16,000	510	0	--	--
Ground Idle	110	10,300	0-16,000	364			

SCHEDULE OF TEST CONDITIONS
150 - HOUR TEST CYCLE

TIME (MINS)	GOVERNOR	MGT,°F	nI	nII CYCLES 11-15	nII CYCLES	TORQUE LB-FT CYCLES 11-15	TORQUE LB-FT ALL OTHER CYCLES
Maximum Power Run							
10	nI	1630 $^{+10}_{-0}$	As req'd	Min gov (1)	104.3%	1575 min (1)	As req'd
5	nI	-	Gnd. Idle	Preset		-	-
Repeat this cycle 3 times for a total of 1 hour							
Stop; restart within 5 minutes (2)							
Maximum Continuous Power Run							
20	nII	1435 $^{+10}_{-0}$	As req'd	104.3%	104.3%	As req'd	As req'd
20	nII	1435 $^{+10}_{-0}$	As req'd	104.3%	104.3%	As req'd	As req'd
20	nII	1435 $^{+10}_{-0}$	As req'd	Min gov (1)	Min gov (1)	1326 min (1)	1326 (1)
Stop; restart within 5 minutes (2)							
Intermediate Power Run							
30	nII	1495 $^{+10}_{-0}$	As req'd	Min gov (1)	104.3%	1326 min (1)	As req'd
5	nII	1405 $^{+0}_{-10}$	As req'd	104.3%	104.3%	As req'd	As req'd
20	nII	1495 $^{+10}_{-0}$	As req'd	Min gov (1)	104.3%	1326 min (1)	As req'd
5	nII	1405 $^{+0}_{-10}$	As req'd	104.3%	104.3%	As req'd	As req'd
Stop; restart within 5 minutes (2)							
Power Transient Run							
5	nI	1495 $^{+10}_{-0}$	Gnd. Idle	Preset		-	-
5	nI						
Repeat this sequence 5 times for a total of 1 hour							
Stop; restart within 5 minutes (2)							
High Torque Incremental Run							
15	nII	-	As req'd	Min gov	104.3%	1300	1300
15	nII	-	As req'd	Min gov	104.3%	1170	1170
15	nII	-	As req'd	Min gov	104.3%	1040	1040
15	nII	-	As req'd	Min gov	104.3%	780	780
Stop start within 5 minutes							
Low Torque Incremental Run							
15	nII	-	As req'd	Min gov	104.3%	520	520
15	nII	-	As req'd	Min gov	104.3%	260	260
15	nII	-	As req'd	Min gov	104.3%	39 max	39 max
15	nI	-	Gnd. Idle	As req'd	As req'd	130 min	130 min
Stop; start within 5 minutes							

NOTES:

(1) Set nII at minimum governing speed or at given torque, whichever is reached first, while maintaining the required MGT.

(2) Shutdown period may be extended when required for any reason. Stop may be eliminated if an unscheduled stop has been made in preceding period. A total of at least 6 starts must be made in each 6-hour cycle.

SCHEDULE OF TEST CONDITIONS
EMERGENCY POWER TEST

Time (mins)	Governor	MGT, °F	nI	nII, %	Torque lb-ft
Power Transient Run					
5	nI	-	Grd. Idle	Preset	-
5	nII	$1495 {}^{+10}_{-0}$	As req'd	104.3	As req'd
5	nI	-	Grd. Idle	Preset	-
5	nII	$1495 {}^{+10}_{-0}$	As req'd	104.3	As req'd
Maximum Continuous Run					
30	nI	$1435 {}^{+10}_{-0}$	As req'd	104.3	As req'd
Intermediate Power Run					
15	nII	$1495 {}^{+10}_{-0}$	As req'd	104.3	As req'd
Maximum Power Run					
5	nI	-	Grd. Idle	Preset	-
10	nI	$1630 {}^{+10}_{-0}$	As req'd	104.3	As req'd
Emergency Power Run					
30	nI	$1670 {}^{+10}_{-0}$	As req'd	104.3	As req'd
Incremental Run					
10	nII	-	As req'd	104.3	1040
10	nII	-	As req'd	104.3	780
10	nII	-	As req'd	104.3	520
10	nII	-	As req'd	104.3	260

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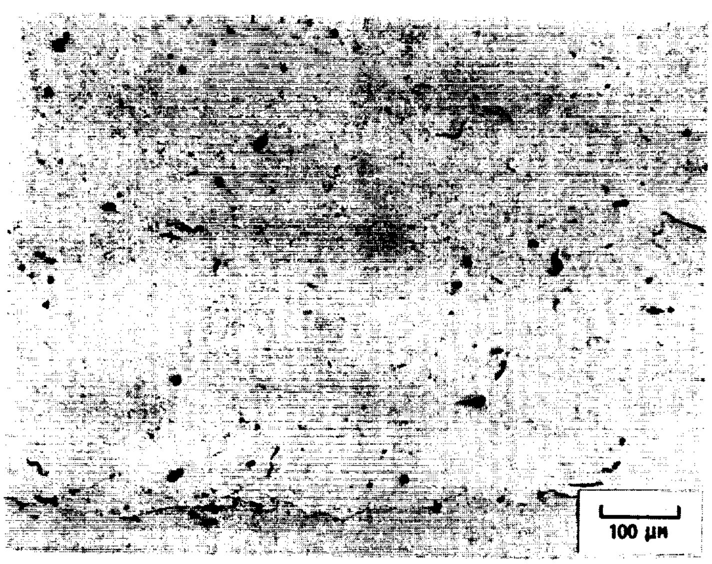
1. Thermal Spraying: Practice, Theory, and Application. American Welding Society, 1985, Ch. 6.5.

2. Metals Handbook, Vol. 1 - Properties and Selections of Metals, 8th Ed., American Society of Metals, 1961, p. 942.

3. Metals Handbook, Vol. 1 - Properties and Selection of Metals, 8th Ed., American Society of Metals, 1961, p. 1101.

4. Standard Test Method for Adhesion or Cohesive Strength of Flame-Sprayed Coatings. ASTM Std. C-633-79, ASTM Book of Standards, 1987.

(A) PARAMETER SET NO. 3 Ar/H_2.



(B) PARAMETER SET NO. 4 N_2/H_2.

FIGURE 1. - STANDARD PHOTOMICROGRAPH OF 52C-NS (88 WT % AL-12 WT % SI).

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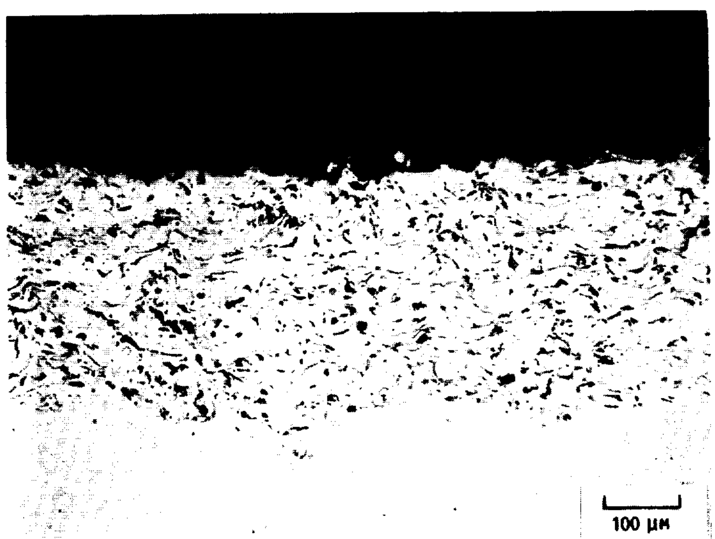
(A) PARAMETER SET NO. 3 Ar/H_2.



(B) PARAMETER SET NO. 4 N_2/H_2.

FIGURE 2. - STANDARD PHOTOMICROGRAPH OF 450-NS (95 WT % Ni-5 WT % Al COMPOSITE).

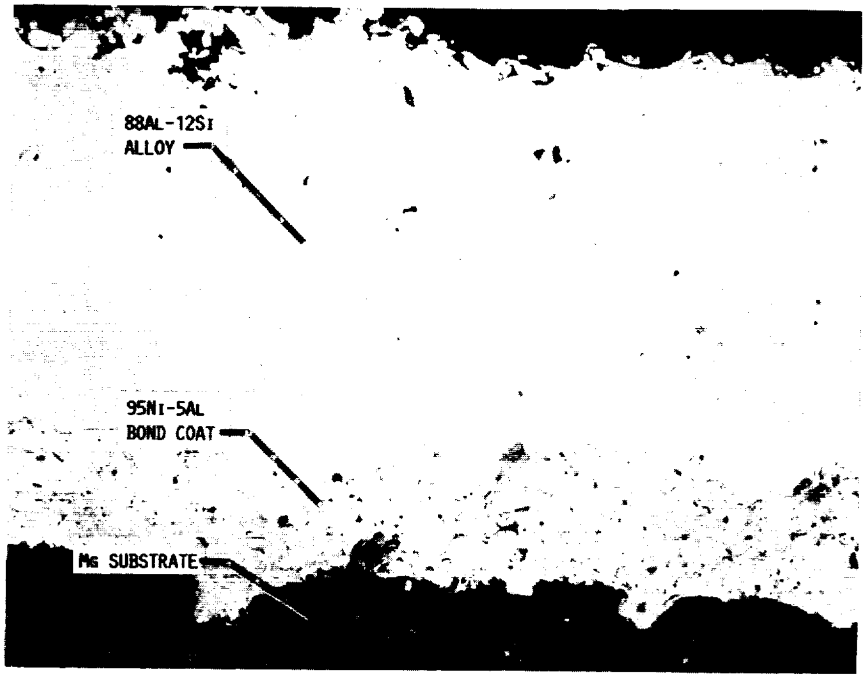


FIGURE 3. - REPRESENTATIVE PHOTOMICROGRAPHS OF A TENSILE SPECIMEN PLASMA SPRAYED AT THE CORPUS CHRISTI ARMY DEPOT.

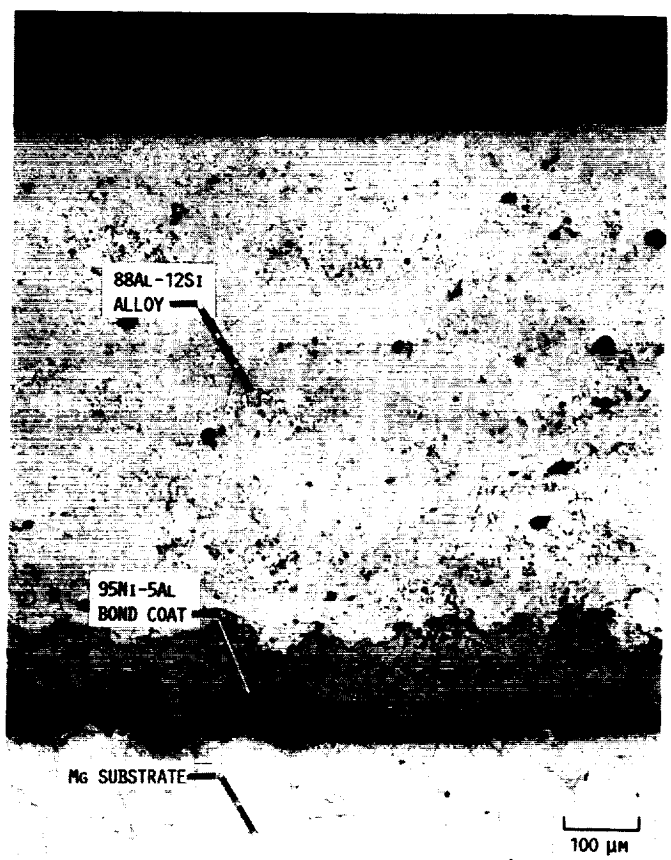


FIGURE 4. - REPRESENTATIVE PHOTOMICROGRAPHS OF A THERMALLY CYCLED SPECIMEN PLASMA SPRAYED AT THE CORPUS CHRISTI ARMY DEPOT.

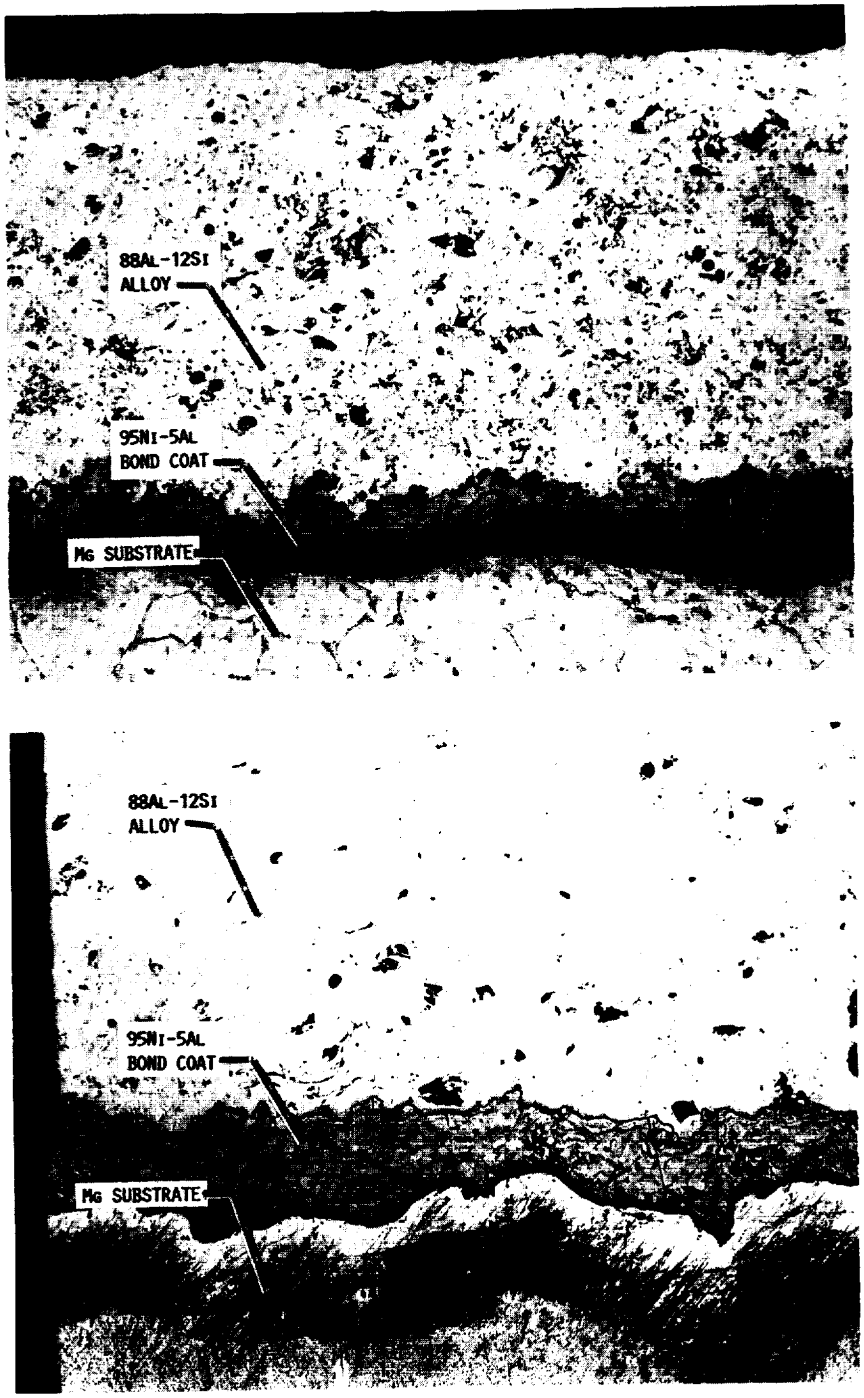


FIGURE 5. - REPRESENTATIVE PHOTOMICROGRAPHS OF SPECIMENS TAKEN FROM THE COMPRESSOR HOUSING THAT WAS IN THE 150-HR ENDURANCE AND 10-HR EMERGENCY POWER TEST. SPECIMENS WERE PLASMA SPRAYED AT THE CORPUS CHRISTI ARMY DEPOT.

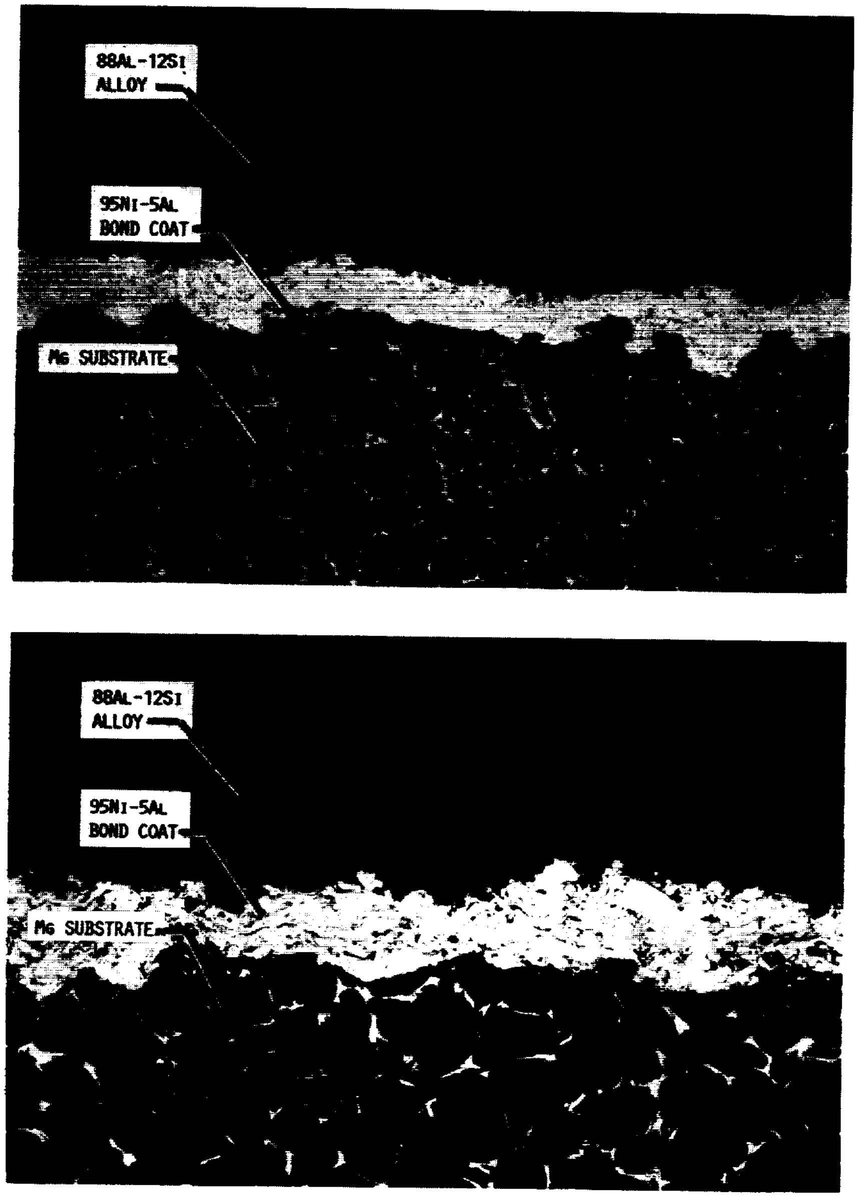


FIGURE 6. - REPRESENTATIVE BACKSCATTERED SCANNING ELECTRON PHOTOMICROGRAPHS OF SPECIMENS TAKEN FROM THE COMPRESSOR HOUSING WHICH WAS IN THE 200 HR FLIGHT TEST. SPECIMENS WERE PLASMA SPRAYED AT THE CORPUS CHRISTI ARMY DEPOT.

Report Documentation Page

NASA
National Aeronautics and Space Administration

1. Report No. NASA TM-101310 AVSCOM TM-88-C-006	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle T55-L-712 Turbine Engine Compressor Housing Refurbishment—Plasma Spray Project		5. Report Date October 1988
		6. Performing Organization Code
7. Author(s) George W. Leissler and John S. Yuhas		8. Performing Organization Report No. E-4301
		10. Work Unit No. 1L162209AH76 505-62-0K
9. Performing Organization Name and Address NASA Lewis Research Center Cleveland, Ohio 44135-3191 and Propulsion Directorate U.S. Army Aviation Research and Technology Activity—AVSCOM Cleveland, Ohio 44135-3127		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001 and U.S. Army Aviation Systems Command St. Louis, Mo. 63120-1798		14. Sponsoring Agency Code

15. Supplementary Notes

George W. Leissler, Sverdrup Technology, Inc., NASA Lewis Research Center Group, Cleveland, Ohio 44135; John S. Yuhas, Propulsion Directorate. Appendix A—T55-L-712 Compressor Housing Refurbishment Procedure by Carl Reitenbach, Propulsion Directorate; George Leissler, Sverdrup Technology, Inc.; and Cliff Darling and George Gilchrist, Corpus Christi Army Depot, Corpus Christi, Texas 78419. Appendix B—Avco Lycoming Test Specificaiton by J. Kozub, Avco Lycoming Textron, Stratford, Connecticut 06497.

16. Abstract

A study was conducted to assess the feasibility of reclaiming T55-L-712 turbine engine compressor housings with an 88 wt% aluminum-12 wt% silicon alloy applied by a plasma spray process. Tensile strength testing was conducted on as-sprayed and thermally cycled test specimens which were plasma sprayed with 0.020 to 0.100 in. coating thicknesses. Satisfactory tensile strength values were observed in the as-sprayed tensile specimens. There was essentially no decrease in tensile strength after thermally cycling the tensile specimens. Furthermore, compressor housings were plasma sprayed and thermally cycled in a 150-hr engine test and a 200 hr actual flight test during which the turbine engine was operated at a variety of loads, speeds, and torques. The plasma sprayed coating system showed no evidence of degradation or delamination from the compressor housings. As a result of these tests, a procedure was designed and developed for the application of an aluminum-silicon alloy in order to reclaim T-55-L-712 turbine engine compressor housings.

17. Key Words (Suggested by Author(s)) Compressor housing refurbishment Turbine engine Plasma spray Aluminum-silicon alloy	18. Distribution Statement Unclassified – Unlimited Subject Category 26

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of pages	22. Price*
Unclassified	Unclassified	44	A03

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161

National Aeronautics and
Space Administration

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Cleveland, Ohio 44135